

The Shoe-Fitting Fluoroscope as a Radiation Hazard

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SUMMARY

Tests of direct beam intensity and stray radiation from shoe-fitting fluoroscopes indicate wide variability of exposure of patrons and salesmen, with some exposures far in excess of standards proposed for safe use of the apparatus.

The principal potential danger is interference with bone growth in children as a result of careless use or uncontrolled dosage of x-ray. Although less likely, there is also some possibility of excessive exposure of shoe salesmen in exceptional circumstances.

The growing probability of increasing use of ionizing radiations warrants vigorous governmental control or possibly elimination of procedures of questionable merit which involve public risk.

THE fluoroscopic shoe-fitting machine has been used in this country for approximately 25 years. During that time hundreds of thousands of adults and children have had their feet exposed at intervals to x-ray beams. Yet, because of the latent period between cause and effect in low dosage radiation, it is impossible at present to determine merely by clinical examination whether or not deleterious influences have been produced by this device. It is also difficult to estimate the probability of harmful effect.

Despite the relatively long experience in the use of the fluoroscopic shoe fitter, it is remarkable that scientific studies on x-ray dosage of the instruments have been published only during the past two or three years.^{11, 6, 4, 10} Current interest in this subject is no doubt attributable to the fact that physicians and health physicists everywhere are beginning to be concerned about every potential source of radiation, because of the possibility that widespread even though mild contamination may result from peaceful utilization of nuclear fission, quite irrespective of the potentialities of the atomic bomb. Also, war-time experience with careless use of portable fluoroscopic devices in industrial medical departments has encouraged increased precaution not only among radiologists but among others who use x-rays as well.

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The investigation here reported was conducted with the cooperation of the staff of the Division of Industrial Safety of the California State Department of Industrial Relations and the Bureau of Adult Health of the California State Department of Public Health.

Since there have been several recent reports of the extent of radiation exposure involved in the use of shoe-fitting fluoroscopes, the question may arise as to the need for an additional report on this subject. The following data are presented principally for three reasons: (1) Radiation intensities were determined for weekly exposures of employees. (2) The observations made and the techniques used for monitoring the shoe-fitting machines provide some basis for the discussion of instrumentation in general. (3) The additional data represent confirmation in another region of the country (the San Francisco Bay area) of findings already established elsewhere,^{11, 6, 4} and provide a wide basis for review of the public health implications of the device in question.

A detailed description of the x-ray shoe-fitting machine is given in the report by Fredrick and Smith.⁶ The instrument consists of an ordinary fluoroscope, the x-ray tube of which is placed near the floor. The opening for the customer's feet is situated between the tube and a fluoroscopic screen, and the light image is reflected to three openings at the top of the apparatus, where the customer and the salesman, as well as a third person, may view the fitting. Usually there is an aluminum filter placed between the feet and the x-ray tube, but this is frequently either worn or absent.⁴ The degree of shielding varies with the apparatus and its maintenance. The most modern type of machine is shielded with lead lining in the box containing the tube, and the eyes of the viewers are protected by means of a leaded glass over the fluoroscopic screen. Fredrick and Smith⁶ report observation of machines with oil-immersed x-ray tubes.

Most of the machines were rated at 7 milliamperes maximum current, although several were operated at higher levels as shown by milliammeters observed during operation. The tubes operated at 50 kilovolts in all instances where kilovoltage was determined. Two home-made machines were found in which no electrical instruments were installed. No attempt was made to determine the physical and electrical factors of the machines since this information has already been well established.⁶ This study was directed principally toward an accurate determination of the intensity and relative dosage to which both employees and customers were exposed in the course of normal operations. Even this purpose was not entirely achieved, since it was impossible to maintain sufficient supervision of the shoe salesmen to determine accurately the degree of exposure without producing a nullifying antagonism on their part.

INSTRUMENTATION

Portable apparatus currently available for the determination of x-ray exposures consists principally of the following: (1) ionization chambers of the pencil dosimeter (minometer or electroscope) type; (2) the ion chamber or ionization rate meters; (3) the dosimeter r-meter; (4) the film badge; (5) the Geiger-Müller counter. Although other investigators have used the dosimeter r-meter for detecting stray radiation, it was considered advisable to use the minometer ionization chambers (Victoreen) for this purpose during the brief periods of operation of the machines. The minometer chambers used have maximum capacities of 10, 100 and 200 mr. Three readings were made at each site in most instances. Excellent reproducibility of results was found and all ionization chamber instruments functioned well under conditions of normal humidity. On foggy and humid days it was impossible to charge the chambers. Victoreen dosimeter r-meter chambers with a capacity of 100 r maximum were used for detecting direct beam radiation.

For measurement of weekly exposure each salesman was provided with two film badges. One of these was to be worn in the trouser watch pocket and the other in a trouser cuff. Sales ladies were requested to place one badge in their clothing near the belt and the other inside a shoe. These were worn for 40 hours weekly and exposure was determined by densitometer readings according to standard technique.

PRIMARY X-RAY BEAM INTENSITY

Measurements were made directly within the shoe-fitting chamber on 40 machines and by use of the dosimeter r-meter (Victoreen). Exposures were timed for 30 seconds. Table 1 indicates the primary beam dosage of the machines tested. Chart 1 shows the distribution of doses and demonstrates graphically the variation from machine to machine. It will be noted that there was a range from 12 to 107 r per minute, with an average of 38.4 r per minute. Although no tests were made with a customer's foot in the apparatus, these values give a conservative approximation of the range of radiation to which skin and tissue may be subjected. It is of interest here to point out that several shoe salesmen volunteered the information that they frequently placed their hands within the fitting opening to demonstrate to parents and customers the nature of the fit or to place the foot in a more favorable position for viewing while another salesman operated the machine. It would be interesting to determine the actual exposure per customer and the amount of time during which shoe salesmen are subjected to stray radiation during the course of the day. In this study no such measurements were possible except for casual observations which indicated that there was little inclination to be satisfied with a single timed exposure. Some of the machines were set for five seconds and others for 20 to 30 seconds, but these times were frequently found to be insufficient

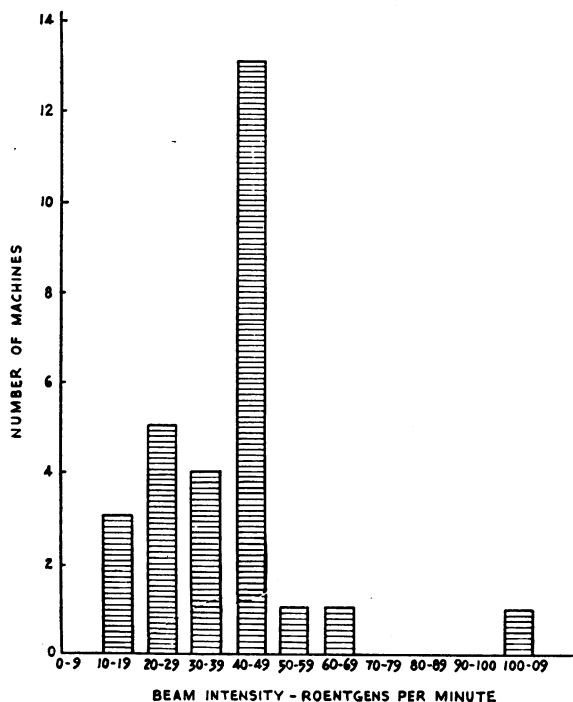


Chart 1.—Distribution of beam intensities in roentgens per minute, measured by placing dosimeter r-meter within shoe-fitting chamber (40 machines).

TABLE 1.—Direct Beam Exposure to Foot*
Roentgens per Minute

Mean	Median	Maximum	Minimum
38.4	40	107	12

* Measured with Victoreen dosimeter r-meter within foot opening.

for customer satisfaction. The possibilities for multiple exposure to the direct beam are obvious when one considers the frequency with which some patrons may go from store to store, at each of which there may be several fittings.

Seventy-seven salesmen cooperated in this part of the study and readings were made of film badges which were worn for one week in each instance. There were several instances in which the film badges were lost or misplaced and these, unfortunately, were usually the film badges placed in the trouser cuffs. Table 2 and Chart 2 indicate the range of dosage in the two parts of the body surveyed. These data are admittedly rough since there were several instances in which it was known that film badges originally placed in the trouser cuff were later placed in the watch pocket and occasionally there were days during which the film badges were not worn at all. This may account for the relatively large number of zero readings reported.

STRAY RADIATION

Chart 3 represents a plan view of a shoe-fitting machine. Points at which measurements were made are indicated by Numbers 1 to 10. The extent of

leakage of radiation about the machine is shown in Table 3 for the various positions tested. These observations were made with Victoreen minometer ionization chambers with capacities of 10, 100 and 200 mr. It will be noted that a high degree of scatter was found at the foot opening of the machine and that fairly high values also were obtained when the instrument was placed beside the foot being examined. Although the leaded glass shield usually protected the eyes, there were some instances in which as much as 9 mr per minute was recorded at the viewing point. This was probably attributable to the fact that the leaded glass was not always placed in proper position and leakage occurred around the margin.

DISCUSSION

This investigation was concerned only with the potential hazard of radiation exposure. It has been pointed out by others that the shoe-fitting fluoroscope is an electrical device supplied by a high-voltage current and that the possibility of electric shock is also involved. In no known instance was adequate maintenance supplied either by the manufacturer or distributor of the machines. Successful continuous operation of the apparatus is dependent chiefly upon the original construction, since

most of the shoe store managers were unfamiliar with possible facilities for repair or testing of machines.

Evaluation of the effect of exposure upon salesmen and shoe store clientele must be based upon established levels of x-ray tolerance. The value of 0.1 r per day was widely accepted for x-ray and gamma ray exposure by most official and other agencies until 1949. At present a new value of 0.3 r per week is suggested as a maximum tolerance.⁹ This value is admittedly conservative, but is based upon the view that during peacetime every effort should be made to maintain as low an exposure to ionizing radiation as can be achieved.

It appears quite obvious from the data presented that shoe store salesmen in general are not ordinarily subjected to doses beyond tolerance limits. In fact, assuming the reliability of the observations

TABLE 2.—Stray Radiation Exposure to Salesmen*

Location	No. of Salesmen	Exposure—mr per week—			Not Detectable
		Mean	100 to 300	10 to 100	
In trouser cuff	58	15.0	2	23	33
In watch pocket	74	7.1	0	22	52

* Measured by film badge densitometer technique.

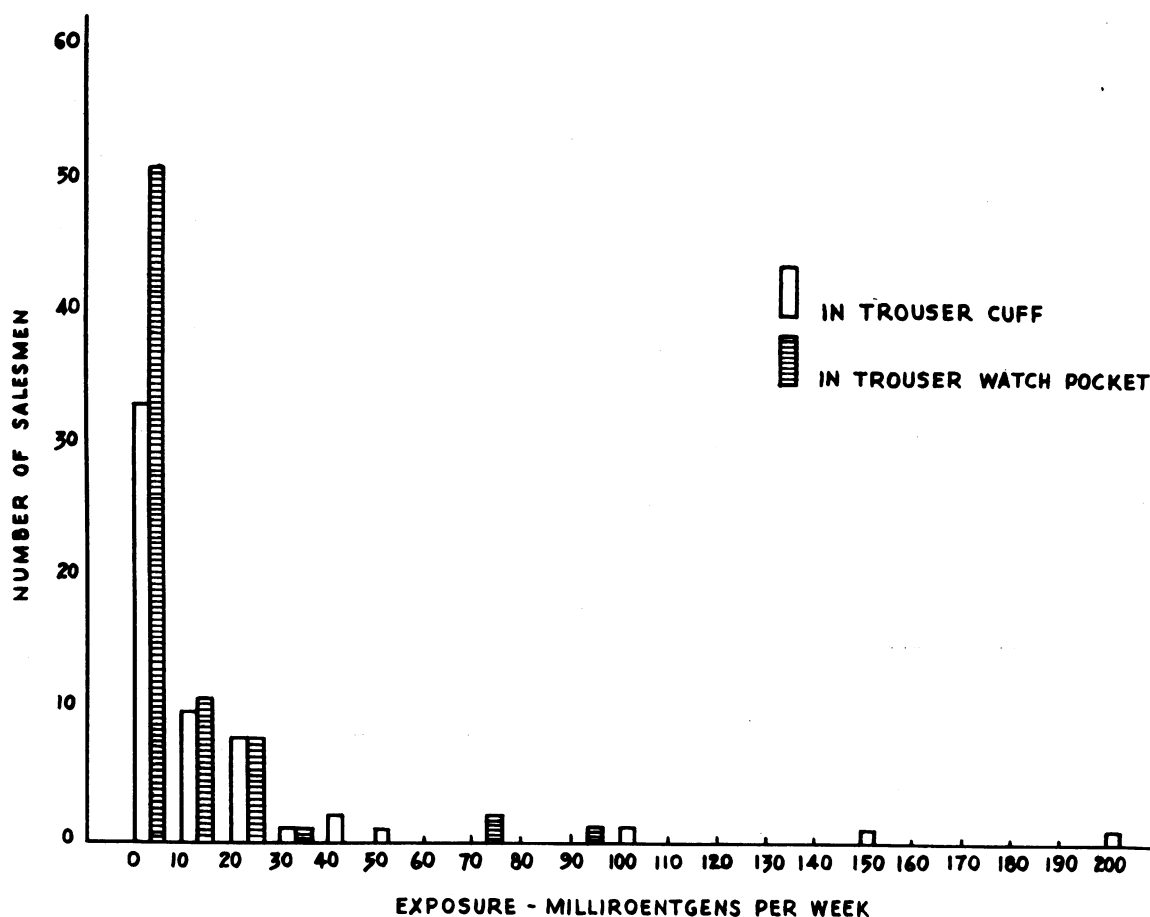


Chart 2.—Range of weekly exposures of shoe salesmen, measured by film badge technique.

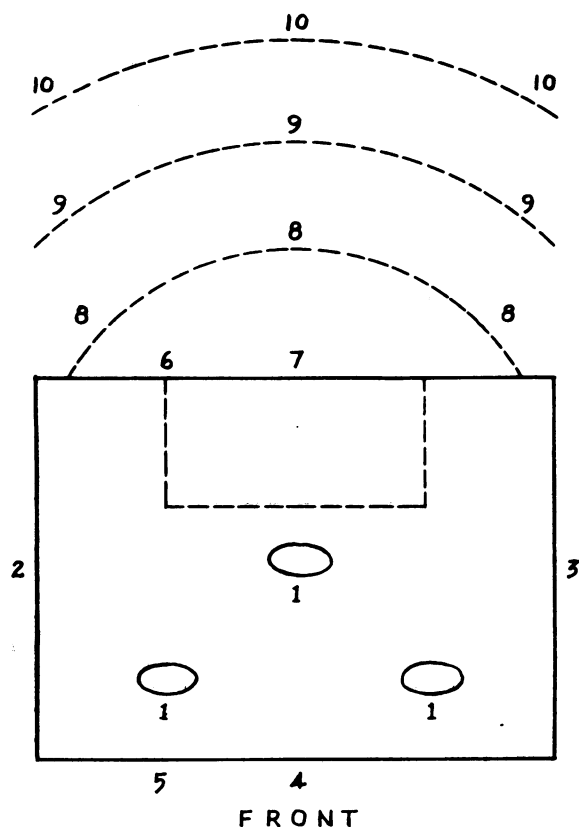


Chart 3.—Plan view of shoe-fitting machine. Numbers refer to points at which stray radiation was measured (see Table 3).

(with the exceptions already noted), most of the salesmen had almost no detectable exposure during the course of a week. Clinical observations were not made but casual inquiry concerning skin effects and other possible radiation injury gave negative results even among salesmen who had used the fluoroscope for as long as five years.

It is equally clear, however, that the customers being fitted usually receive a very substantial dose of radiation. While the feet admittedly represent only a small proportion of the total body tissue, and, therefore, the total dosage may not often be of significance so far as systemic effect is concerned, potentialities for skin damage or injury to the bone structures of a growing foot are undoubtedly present. The American Standards Association² has recommended a limit of 2 r per exposure for shoe-fitting machines. On the basis of a 20-second exposure the values reported by various observers would be as shown in Table 4.

It may be anticipated that the suggested limit of 2 r per fitting will usually be greatly exceeded in practice. However, evaluation of hazard should depend upon more than an arbitrary limit, and evidence of potential harm must be more thoroughly considered.

According to Ellinger,⁵ "On the basis of present knowledge it must be assumed that depth doses of 150 r in infants and 300 r in children are capable

TABLE 3.—Stray Radiation Around Machine

Position (See Chart 3)	Total No. Readings Made	Exposure—mr per Minute of Operation				
		Mean	100- 400	10- 100	1-10	Not De- tectable
1. Eyepieces.....	24	1.0	0	0	4	20
2. Floor—left side.....	38	4.1	0	6	6	26
3. Floor—right side.....	37	1.4	0	1	8	28
4. Floor—front.....	37	1.9	0	3	8	26
5. Operator's switch.....	22	3.7	0	4	2	16
6. Beside foot.....	18	100.0	10	8	0	0
7. At opening.....	32	247.8	32†	0	0	0
8. 1 ft. from opening.....	22	60.2	4	18	0	0
9. 2 ft. from opening.....	22	22.5	0	20	2	0
10. 3 ft. from opening.....	11	23.4	1	7	3	0
6 ft. from opening.....	11	3.5	0	1	3	7

* Measured with minometer ionization chamber pencils.
† Readings of 400 mr or above on seven machines.

TABLE 4.—X-ray Doses for 20-second Fitting

Observer	Maximum Dosage (r)	Mean Dosage (r)
Williams ¹¹	116.0	
A.M.A. Editorial ¹	46.7	
Fredrick and Smith ⁶	25.0	14.3
Lewis and Caplan.....	35.7	12.8

of causing growth disturbances." There is good evidence that the epiphyses, rather than the shafts of bones, are the susceptible areas. The potentialities for damage are quite clear when a single 20-second exposure to the shoe-fitting machine may exceed one-third of the hazardous dose for children.

Aside from specific epiphyseal damage, there is another consideration which must arise in any radiation exposure. Lapp and Andrews⁸ point out: "Whatever the permissible exposure may be, all workers must recognize that any amount of radiation is potentially dangerous and should be avoided . . . Present evidence indicates that at least some radiation injuries are statistical processes that do not have a threshold. If this evidence is valid, there is no exposure which is absolutely safe and which produces no effect." This point of view is thoroughly supported by recently reported observations that the incidence of cancer among exposed mice begins to rise with the lowest measurable dosage of ionizing radiation. It would seem advisable, therefore, that voluntary exposure should be limited to cosmic radiation, essential diagnostic radiography and natural or induced environmental sources of radioactivity.

CONCLUSION

The shoe-fitting fluoroscope is not an instrument with obviously hazardous potentialities. It has long been used and no direct clinical evidence of harm has yet been established. However, any x-ray apparatus represents a source of insidious harmful radiation, the use or abuse of which may lead to significant damage, often without recognition of clearcut causal relationship.⁷ The early history of the use of diagnostic x-irradiation without precaution and the subsequent appearance of skin and neoplastic changes after years of latency should provide ade-

quate warning against careless exposure to any source of ionizing radiation.

Sufficient information has now been accumulated to prove that the fluoroscopic shoe-fitting machine represents a potential, if not obvious, hazard. The question which must be answered by health authorities is whether these machines should be subjected to strict regulation or eliminated entirely. The answer to this question depends in part upon a consideration of the usefulness of the devices. If fluoroscopy is essential to shoe fitting, its use can probably be rendered safe. This will necessarily involve training of personnel and frequent inspection, the efficacy of which is always limited. In this connection it is interesting that of the 77 salesmen interviewed at least half were of the opinion that the machine was not of use in scientific shoe fitting. Most of them were of the opinion that it was chiefly useful for sales promotion and only a small minority favored its use for more satisfactory fitting, particularly of children. In several instances shoe-fitting machines were found in shops where they had long been relegated to disuse.

No attempt will be made to settle the issue of policy, the determination of which should lead to proper action on the part of public health or governmental industrial hygiene agencies. (See resolution adopted by the American Conference of Governmental Industrial Hygienists.¹) If regulation is the procedure of choice, the "requirements for the safe operation of fluoroscopic shoe-fitting devices" incorporated in the article by Fredrick and Smith⁶ are recommended for consideration.* In order to operate at the suggested value of 12 r per minute, however, it will be necessary that machines be maintained in good order. The lower intensities suggested for women and children are advisable but the difficulty of supervising proper use of a graded scale of exposure must not be underestimated.

* On March 1, 1948, "Regulations Governing the Operation and Maintenance of Apparatus Used for Shoe-Fitting Fluoroscopy" became effective under the sanitary code of the City of New York.³ These specify a maximum permissible dose of 2 r per exposure, limit the number of exposures to three per day and 12 per year. Stray radiation exposure of employees is not to exceed 12.5 mr per hour.

The Detroit department of health requirements⁶ are in general comparable to those of New York, but, instead of specifying dosage per exposure, permit a direct beam intensity maximum of 12 r per minute for five seconds (less for women and children) and a maximum of five fittings per day and 20 per year. At 12 r per minute, five fittings of five seconds each result in a dose of 5 r.

Although, as has been stated, no attempt will be made here to resolve the basic question of policy, the arguments in favor of elimination of the shoe-fitting fluoroscope can be very simply stated. The difficulties of inspection and maintenance are well known to safety and health agencies. Machines inspected today may be modified by removal of screens or filters and rendered extremely hazardous tomorrow. Furthermore, the most extensive set of regulations will not prevent careless exposure of the hands, excessive irradiation of the growing child's foot, or other improper use since it is difficult to establish fear of a harmful material as intangible as an x-ray. In view of the probability of improper use and because of uncertain knowledge as to the danger of cumulative small dosage of x-ray, it is clear that a very good case can be made for the removal of these devices from commercial shoe stores. This is particularly true in view of the lack of proof of their merit as scientific devices for fitting shoes.

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